U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

AD-A029 451

TECHNOLOGY AND PHYSICS OF INFRARED AND POINT CONTACT DIODES

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 9, 1976

257131

ADA029451

RADC-TR-76-2?
Semi Annual Technical Report No. 4
June 1976

TECHNOLOGY AND PHYSICS OF INFRARED AND POINT CONTACT DIODES

Department of Physics
Massachusetts Institute of Technology
Cambridge, Mass. 02139

Approved for Public Release;
distribution unlimited.

Sponsored by
Defense Advanced Research Projects Agency
ARPA Order No. 2618

ROME AIR DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
GRIFFIS AIR FORCE BASE, NEW YORK 13441

TECHNOLOGY AND PHYSICS OF INFRARED
AND POINT CONTACT DIODES

Contractor: Massachusetts Institute of Technology
Contract Number: F19628-74-C-0182
Effective Date of Contract: 24 January 1974
Contract Expiration Date: 28 February 1977
ARPA Order No.: 2618
Program Code Number: 5D10
Period of Work Covered: 1 November 1975-30 April 1976
Principal Investigator: Ali Javan
Phone: 617-253-5088
Project Engineer: Dr. Audun Hordvik
Phone: 617-861-4927

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Defense Advanced Research Projects Agency or the U.S. Government.

This report has been reviewed by the RADC Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public including foreign nations.

This report has been reviewed and is approved for publication.

APPROVED:

Audun Hordvik

AUDUN HORDVIK
Contract Monitor

Do not return this copy. Retain or destroy.

MIL-STD-847A
31 January 1973

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: RADC-TR-76-234
2. GOVT ACCESSION NO:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): Technology and Physics of Infrared and Point Contact Diodes
5. TYPE OF REPORT & PERIOD COVERED: 1 Nov. 75 - 30 Apr 76 Scientific Interim
6. PERFORMING ORG. REPORT NUMBER: Semi-Annual Technical Report #4
7. AUTHOR(s): Ali Javan
8. CONTRACT OR GRANT NUMBER(s): F19628-74-C-0182
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Department of Physics, Mass. Inst. of Tech., Cambridge Ma. 02139
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 2001-01-01, 61101E
11. CONTROLLING OFFICE NAME AND ADDRESS: Defense Advanced Research Proj. Agency - 1400 Wilson Blvd. Arlington, VA 22209
12. REPORT DATE: June 9, 1976
13. NUMBER OF PAGES: 19
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Deputy for Electronic Technology (RADC(ETSL)), Hanscom AFB, MA 01731. Contract Monitor: Audun Hordvik
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES: This Research was sponsored by the Defense Advanced Research Projects Agency, ARPA Order 2618
19. KEY WORDS (Continue on reverse side if necessary and identify by block number): Tunneling resonances, dielectric formation, oxide studies, photoemission.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Repair work on our liquid helium has been successfully completed. A pump and pumping lines have been installed which enable us to pump the helium to cool it below the lambda point and perform our experimental work in superfluid helium.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Report Documentation Page.

PRICES SUBJECT TO CHANGE

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

Cont. Block #20

A tube and mirrors have been installed from the argon and dye laser room to the diode testing area. This permits greater availability of the laser and more working space near the beams.

Additional lead on aluminum diodes were evaluated at liquid helium temperature. Interpretation of these and earlier runs indicates:

a. For low non-saturating power levels from RF through visible, junction responses at low bias (less than 20 mv) were identical.

b. For higher biases with the junction in superfluid helium, resonances were not detectable at frequencies above RF. However, a constant offset from zero was observed (opposite senses for opposite biases) which seemed to increase with increasing radiation frequency. This is taken as an indication of photoresponse for electrons overcoming the superconducting gap.

An oxidation study was conducted on nickel which demonstrated that 400 square micrometer junctions from 100 ohms through 1 megohm can be made. Those junctions are moderately stable over a few days in room ambient. Lead on tin junctions have been made in the few kilohm range.

Real time V-band and 337 μm holographic receptors have been designed and masks are being fabricated.

Measurements are in progress on MOM (tungsten on nickel) point contact diodes to evaluate their effective antenna resistance as a function of length. The effective diode resistance is varied by changing whisker pressure and response is maximized with respect to whisker orientation in the focused laser beam. Antenna resistance is obtained by adjusting parameters on a curve of diode resistance versus rectified voltage.

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

TABLE OF CONTENTS

1. SUMMARY

Repair work on our liquid helium dewar has been successfully completed. A pump and pumping lines have been installed which enable us to pump the helium to cool it below the lambda point and perform our experimental work in superfluid helium.

A tube and mirrors have been installed from the argon and dye laser room to the diode testing area. This permits greater availability of the laser and more working space near the beams.

Additional lead on aluminum diodes were evaluated at liquid helium temperature. Interpretation of these and earlier runs indicates:

a. For low non-saturating power levels from RF through visible, junction responses at low bias (less than 20 mv) were identical.

b. For higher biases with the junction in superfluid helium, resonances were not detectable at frequencies above R F. However, a constant offset from zero was observed (opposite senses for opposite biases) which seemed to increase with increasing radiation frequency. This is taken as an indication of photoresponse for electrons overcoming the superconducting gap.

An oxidation study was conducted on nickel which demonstrated that 400 square micrometer junctions from 100 ohms through 1 megohm can be made. These junctions are moderately stable over a few days in room ambient. Lead on tin junctions

have been made in the few kilohm range.

Real time V-band and 337 μm holographic receptors have been designed and masks are being fabricated.

Measurements are in progress on MOM (tungsten on nickel) point contact diodes to evaluate their effective antenna resistance as a function of length. The effective diode resistance is varied by changing whisker pressure and response is maximized with respect to whisker orientation in the focused laser beam. Antenna resistance is obtained by adjusting parameters on a curve of diode resistance versus rectified voltage.

2. INTRODUCTION

Preliminary work in this laboratory has shown that tunneling characteristics of metal-oxide-metal junctions are essentially independent of frequency as long as photon energy is less than the barrier height. Recent calculations show the effects of circuit parameters on response of antenna/diode combinations; the junction capacitance is responsible for roll off in the infrared. Capacitance reduction requires shrinking junction size, hence the need for micron and submicron geometries. Photo emission (over the barrier rather than tunneling) and thermal effects dominate the response in the visible region. It seems likely that photoemission is a fast effect and can be used for visible mixing.

Important elements of device merit are junction nonlinearity and even negative resistance which may be enhanced by choice of materials, techniques of application and operating temperature.

3. DEWAR REPAIR

Our liquid helium dewar has been repaired and used in a number of low temperature runs. This dewar is equipped with quartz windows in each of three ports and has in the past been subject to failure seemingly at the most critical times. The manufacturer found three leaks, one of which occurred only at low temperature. Repair has permitted us to make our runs with no problem from the dewar, and only routine pump downs of the vacuum chamber.

4. SUPERFLUID HELIUM

In an attempt to maintain junctions under test at a constant temperature the helium in the dewar was pumped. After increase in the size of the pumping line and of the pump, it became possible to pump the liquid helium to below the lambda point in about 40 minutes. Although there is a thermal match barrier between the junction and the helium subsequent work has demonstrated that superfluid helium (below the lambda point at 2.1° K) does maintain the sample at a much more uniform temperature than "normal" liquid helium.

5. EXTENSION OF LASER LAB

A tube and sets of mirrors have been installed from the argon and dye laser room to the diode testing area. This has permitted much greater availability of the argon laser and considerably increased working space near the laser beams.

6. LOW TEMPERATURE RESPONSE OF $Al-Al_2O_3-Pb$ JUNCTIONS

Rectification characteristics of $Al-Al_2O_3-Pb$ junctions were studied at 4_o2^oK (liquid helium) and 2^oK (helium pumped below the lambda point). In both cases the lead was superconducting and the aluminum was "normal." Measurements were made at 10 MHz, X-band (microwave), 337 μm (HCN laser) and with laser light in the visible.

The junctions were made by evaporating a 20 μm wide strip of aluminum to a thickness of 500 Å, oxidizing it in a few torr of pure oxygen for half an hour and then evaporating a thick 20 μm wide strip of lead across the oxidized aluminum. Resistances at 50 mV DC ranged from a few hundred to a few thousand ohms. RF was coupled to the junctions by the leads through the dewar top while the higher frequencies were beamed through the dewar windows.

In the low bias (0-20 mv) region responses to low intensity radiation of all wavelengths were the same. The superconducting transition at about 1.5 mv as well as phonon mode excitations were observed. (See Fig. 1) Widths and positions of each resonance were the same. Power saturation occurred for laser powers greater than one milliwatt. Similar saturation was observed with RF and at X-band.

At biases greater than about 20 mv and temperatures below the lambda point, tunneling resonance responses to visible laser radiation could not be detected, however there was an offset from zero which is roughly constant with bias voltage but has the same polarity as the applied bias. (See Fig. 2) Qualitatively, this response seemed to increase with increasing radiation frequency and it is taken as an indication of photo-response for electrons overcoming the superconducting gap. At temperatures above the lambda point, the effect of the resonances is to give a distorted bell curve. Since these observations are made with mechanically chopped radiation and amplified with coherent detection on a lock-in, this appears to be the difference between normal tunneling response at two different temperatures.

Lead on aluminum diode response to 10 MHz radiation was observed at 4.2 $^{\circ}$K in the presence of argon laser radiation. It was observed that one mw. of radiation detectably reduced the structure of the 10 MHz pattern whereas 100 mw reduced it to less than 10%. Sensitivity of the response due to super-conducting characteristics of lead was only slightly more reduced than the high field anomalies.

The model we currently use to explain these observations is that superfluid helium maintains the junction at nearly the same temperature, with and without radiation so that I-V curves are nearly parallel. But above the lambda point the heating causes considerable temperature rise with consequent broadening of the resonance; the lock-in displays the difference of these two curves.

Very little X-band power is coupled through the windows into the dewar. This is not enough to observe the higher bias resonances. However, the I-V characteristics due to the superconducting gap, at about 1.5 mV are extremely sharp and make the junction a very sensitive detector; these resonances have been seen at X-band despite the very low incident power level.

7. METAL OXIDATION TECHNIQUES

To study oxidation characteristics of nickel, several 20 μm x 20 μm junctions were fabricated. Nickel was evaporated first and the slide heated on the hot plate. Four runs gave the following resistances as a function of oxidation time.

Junction	Oxidation Time	Resistance Range
Ni-NiO-Pb	0 hours	short
Ni-NiO-Pb	3 hours	81Ω - 130 Ω
Ni-NiO-Ni	4 hours	680Ω - 910Ω
Ni-NiO-Pb	15 3/4 hours	320 KΩ-900 KΩ

Resistances typically increased by a quarter in the 24 hours following their preparation.

A lead on tin junction was made with three hours of hot plate oxidation. Resistances were 4.3 KΩ and 8.2 KΩ. They increased by half in the 17 hours after fabrication. This junction should be operable in the high microwave region and as a negative resistance device below 3.5°K.

8. MASK FABRICATION

A real time V - band holographic receptor was designed, rubylith cut and sent out to be photoreduced. Masks have been made for photo production. Units were started but it was discovered that there was lack of metal adherence for the lift off step. We have found that glow discharge cleaning is required before metal deposition; parameters were varied and 200 μm of oxygen for 5 minutes at 2 mA seems a good first approximation. Substrates must be clean, but no special initial surface preparation appears necessary when the glow discharge is used. Some exposure problems seem to be present due to reflection from the substrate holder of the mask aligner. This will be corrected with a black anodized holder, in fabrication.

A four element holographic sensor mask for 337 μm work has been designed and is being fabricated. (See Fig. 3)

9. POINT CONTACT ANTENNA RESISTANCE

Measurements are in progress on MOM (tungsten on nickel) point contact diodes to evaluate their effective antenna resistance as a function of length. The 10 μm diameter tungsten whisker acts as a multiwavelength antenna with effective antenna resistance of R_a. The tunneling barrier presents a junction resistance of R_d at the DC bias voltage. The point is small enough that we can neglect capacitive effects so that the voltage rectified across the diode is:

$$V_d = V_i\left(\frac{R_d}{R_a + R_d}\right)^2$$

A value of R_a can be determined by adjusting parameters on a curve of R_d vs. V_d.

A characteristic of thin dipole antennas is that the capture cross section has resonances near $n\lambda/2$ (integral values of n). The antenna resistance for very long antennas is 163 Ω.

Antenna resistances were calculated for various length whiskers with 337 μm radiation from the HCN laser. This radiation was focused onto the junction region of the diode with a teflon lens. The rectified signal was then maximized by adjusting orientation to the peak of the largest antenna lobe. R_d is varied by changing the diode contact pressure on the nickel post. To maintain a constant tunneling barrier height, all data for an R_a calculation must be taken without moving the whisker on the nickel post.

The experimental results for long antennas (longer than about 5 λ) are in agreement with the theoretical expectations ($R_a \simeq 160\ \Omega$). Data for other antenna lengths are still being taken and evaluated.

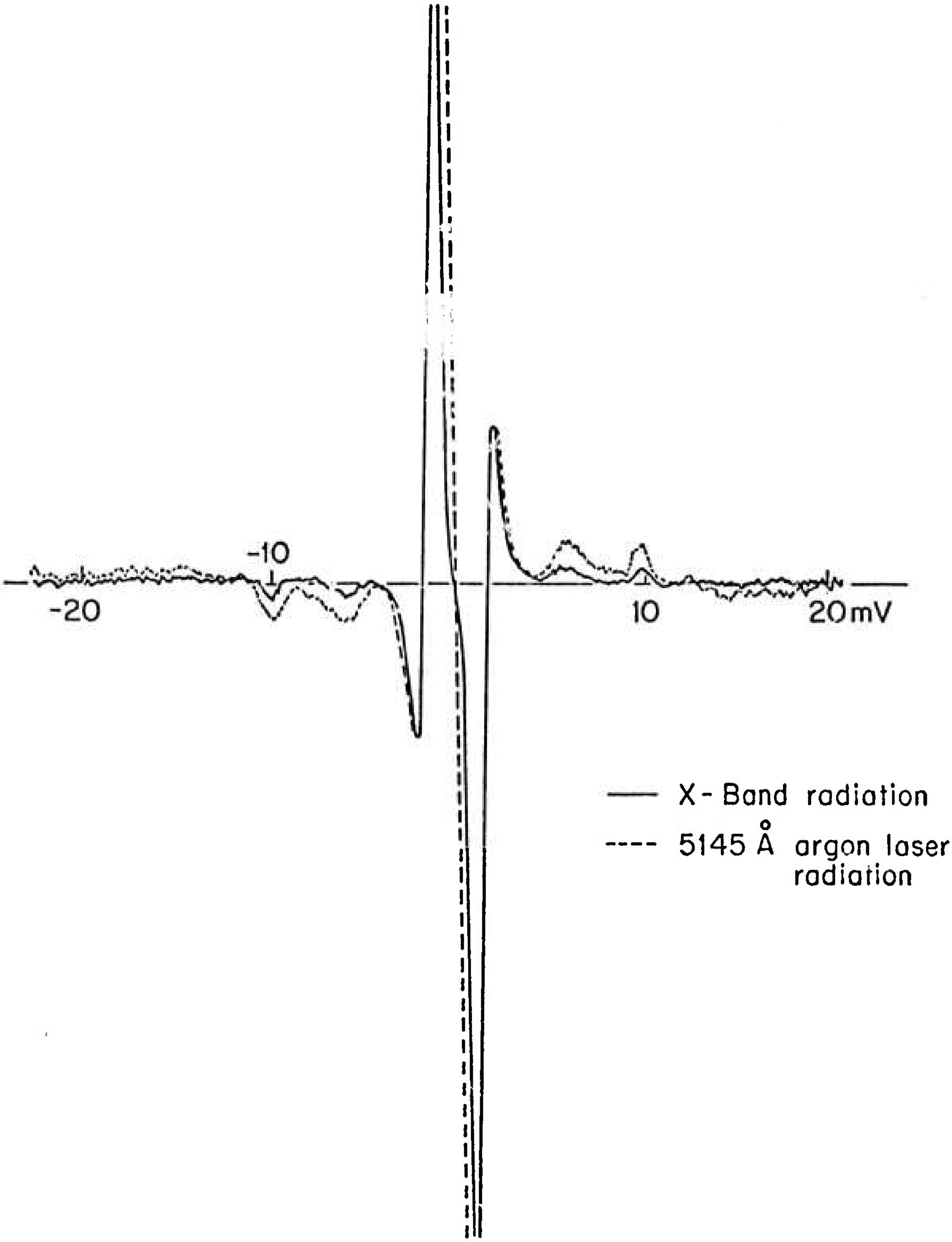

Fig. 1. $Al\text{-}Al_2O_3\text{-}Pb$ diode responses at liquid helium temperature (2^oK) in the low bias region. (0-20 mv). The argon radiation was adjusted to make first satellite peaks of the same height. In both cases, the radiation was below saturation.

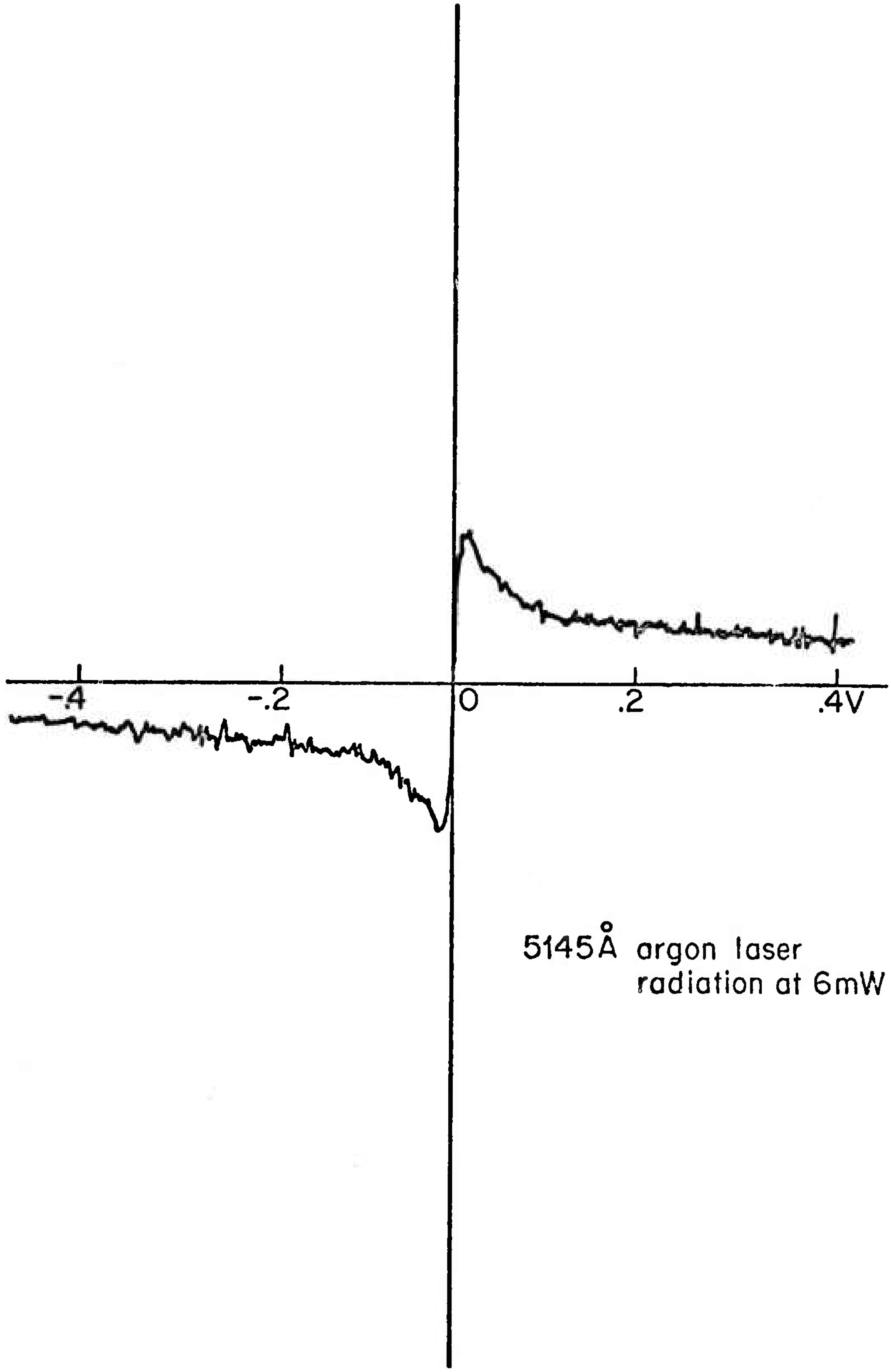

Fig. 2. $Al-Al_2O_3-Pb$ diode responses in superfluid liquid helium at biases to $\pm 0.4V$. The laser focus is centered on the 20 μm square junction. The vertical at zero bias is due to the superconducting transition. Note that the offset approaches a constant value for bias greater than 0.1V.

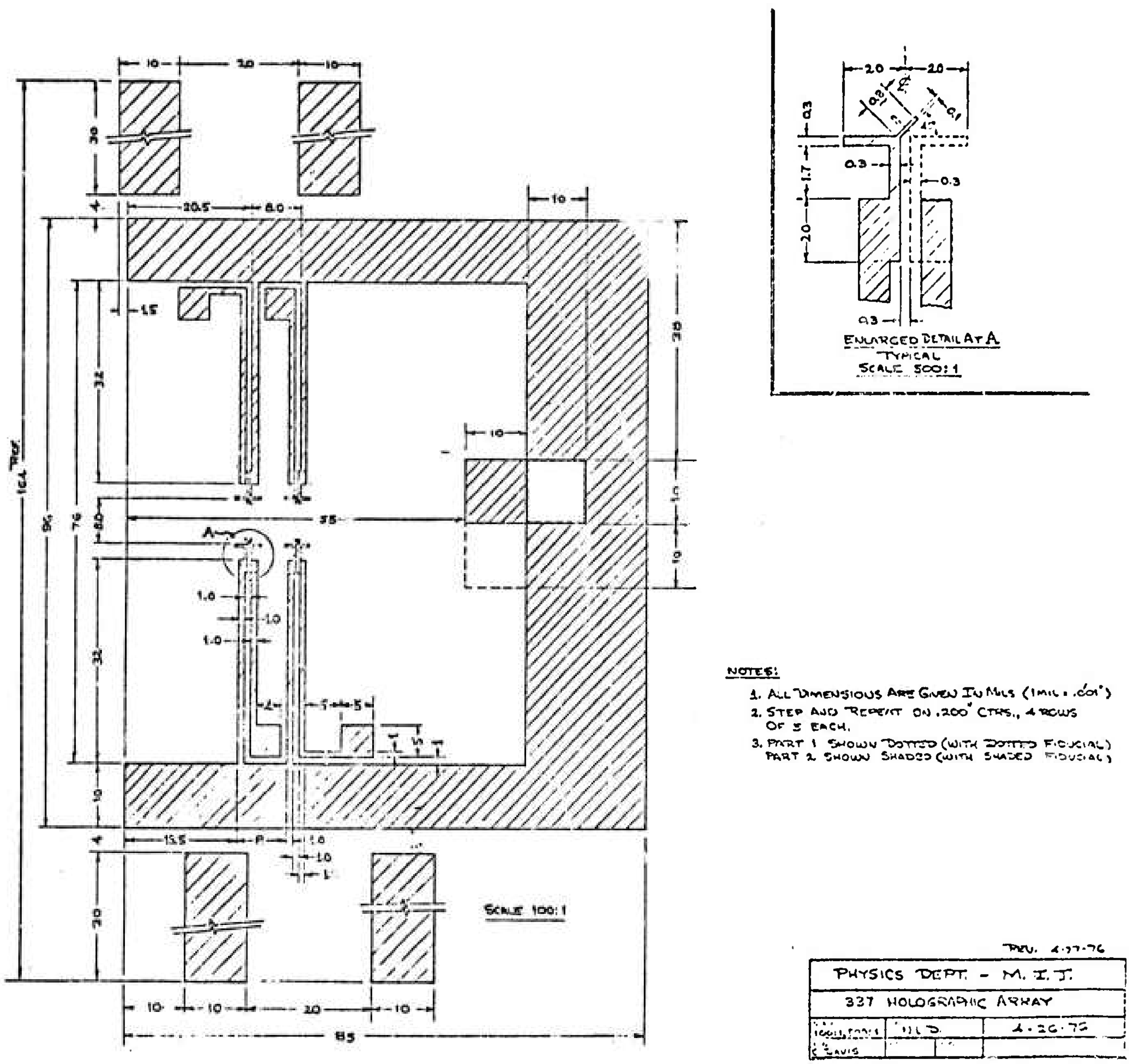

Fig. 3. Drawing for 337 μm four bit holographic array.

MISSION
of
Rome Air Development Center

RADC plans and conducts research, exploratory and advanced development programs in command, control, and communications (C^3) activities, and in the C^3 areas of information sciences and intelligence. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.

Printed by
United States Air Force
Hanscom AFB, Mass. 01731